Workshop on "Measuring techniques for steady state and transient multiphase flows"

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The second workshop on "Measuring Techniques for Steady State and Transient Multiphase Flows" took place at the *Forschungszentrum Rossendorf (FZR)* from 24 - 25 September 1998. This series of meetings was initiated by the Institute for Safety Research of the FZR and by the Institute of Process Technology, Process Automation and Measuring Techniques of the *Hochschule für Technik, Wirtschaft und Sozialwesen (HTWS) Zittau/Görlitz*. The workshop was supported by the *Deutsche Gesellschaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie (DECHEMA)* and the Section "Thermo and Fluiddynamics" of the *Kerntechnische Gesellschaft*. Three main lectures and 13 technical papers dealt with measuring techniques such as optical and radiometric methods, impedance measurements, hot film probes and model-based methods for the measurement of important quantities in two or multiphase flows, such as phase fractions, particle size, velocities, material exchange and concentration of components.

F.-P. Weiß (Forschungszentrum Rossendorf) gave a warm welcome to the 45 participants from industry, research centers and universities. He emphasised, at the same time, the interdisciplinary nature of the meeting, which brought together specialists from areas of both the chemical and nuclear research.

C. Tropea (Technische Universität Darmstadt) opened the session on optical methods with his central lecture on new developments in this field. In the course of his lecture, he summarized the global approach towards developing measuring techniques for droplet flows as follows: (1) mathematical description of shape and distribution of the droplets, (2) mathematical modelling of the light scattering on the particles, i.e. modelling of the detector signal for given measuring quantities, (3) selection of the observable parameters and resolution of the inverse system, i.e. reconstruction of the measuring quantities from the observables and (4) description of the technical realisation. After a summary of the main measurement tasks to be carried out on a droplet flow and of the existing laser methods (e.g. Laser Doppler Anemometry (LDA), Particle Imaging Velocimetry (PIV), Rainbow Methods), emphasis was placed on the measurement of particle size distributions (3-Detector Phase Doppler Particle Analyser (PDPA), Dual Mode PDPA, Planar PDPA). For spherical droplets, state of the art technology for the modelling of light reflection and scattering was reported. Difficulties arise, when different reflection and scattering modes are superposed. When scattering is measured in two different planes, deviations from the spherical shape can be quantified. This permits the characterisation of, for example, droplet oscillations. Irregular particle shapes and clusters of particles represent a great challenge to the further development of PDPA. An extension of the method to be found in the dual burst PDPA, which provides the refraction coefficient together with the particle size. This also permits measurement of further properties of the liquid phase.

R. Kulenovic and *M. Groll* (Universität Stuttgart) compared different methods for the evaluation of Laser-Speckle Photogrammes (LSP). After an introduction to this method, which is usually applied in material science (vibration and deformation analyses) and in fluid mechanics (velocity, pressure and temperature measurement), the paper focused on Digital Laser-Speckle Photogrammetry (DLSP). The so-called specklegrammes are recorded with a CCD camera and evaluated by means of an image processing software. DLSP has the advantage to replace the complicated and inaccurate technique of speckle photogrammetry carried out with traditional photo plates, along with the process of the optical reconstruction. At the same time, the resolution is lower due to the lower resolution CCD matrix (100 lines/mm) by comparison with an holographic film (5000 lines/mm).

J. Kumpart, *M. Michel*, *O. Fiedler* and *K. Chrisofori* (Technische Universität Hamburg-Harburg) reported on the use of spatial filters for local velocity measurements. The method is based on the filtering effect of mesh-like periodical light receiver structures, which are inserted into a flow in the form of a probe. The probes are applied in industry mainly to determine the velocity and length of moving surfaces. If the object is properly illuminated, local velocities in multiphase flows containing high concentrations of solid particles, or in optically dense liquids, can be measured. The method is intrusive within the actual measuring volume in front of the probe, the probes lead to an distortion of the velocity profile, and this has to be taken into account in calibration or mathematical modelling carried out to determine the flow around the probe. Where this is not done, significant measuring errors can occur. Finally, the authors reported on the application of the probes for the measuring of particle velocity in a fluidised bed. Measurements were carried out in an experimental mock-up at room temperature, as well as in an industrial furnace (at temperature of approx. 850° C). At such high temperatures, the emission of particles itself provides the necessary light source.

The contribution of *S. Gomes*, *D. Pfleger*, *N. Gilbert* and *H.-G. Wagner* dealt with the flow regimes in bubble columns. The work is part of the ADMIRE programme (Advanced Design Methods for improved Performance of Industrial gas-liquid Reactors) of the EU. The experiments were conducted in a rectangular bubble column with a height of 1 m, a width of 0.2 m, and a depth of 0.05 m. The bubble flow in the column is unstable. Time-dependent velocities for both liquids and gases were measured. For the gas phase, the Doppler shift of the signal reflected by the bubbles was used. The liquid velocity was measured by means of the sound velocity. The results show a good level of agreement with Laser Doppler Anemometry (LDA) and Particle Tracking Velocimetry (PTV) measurements. PTV can be used to measure both gas and liquid velocities. The latter require the use of tracer particles.

F. Hensel (Forschungszentrum Rossendorf) reported on the imaging technique of Positron Emission Tomography (PET) which originates in the field of nuclear medicine. Typical PET positron emitters like ^{11}C, ^{13}N, ^{15}O and ^{18}F can be substituted for naturally occurring isotopes, in a wide range of organic compounds. The focus was on an experiment aimed at studying the mixing of a tracer in a bubbly flow in order to determine the dispersion coefficient for the tracer. The flow was generated in a narrow tank, simulating a special bubble column. The tank is located in the center of a double-headed PET detector system. The bubbly flow was generated either by means of air injection or an H_2O_2 decomposition reaction. The data evaluation process uses a midplane backprojection of the registered events, which is appropriate to the narrow tank geometry. Using this algorithm, a time resolution of about 500 ms was achieved, under application of tracer activities of about 10 MBq. From the history of the midplane intensity distributions, the dispersion coefficient was determined. To conclude the discussion of the future efforts in the field of non-medical PET applications, a tomograph for the investigation of transport phenomena in bubble columns was presented. With this instrument, the behaviour of surfactants labelled with PET nuclides will be investigated. Transport processes in bubbly flows and foams would seem to be highly appropriate subjects for PET tracer techniques.

In the second main lecture, *V. Teschendorff* (Gesellschaft für Anlagen- und Reaktorsicherheit) specified the need for detailed measurements on two-phase flows from the point of view of reactor safety research. The author pointed out the necessity for continued development of simulation tools. State of the art technology is represented in this field by thermal hydraulic system codes (e.g. ATHLET, RELAP), which are based on 1-D, five or six equations formulation of the balances for mass, energy and momentum. The reliability of the simulation results is limited in cases where three-dimensional and complex flow situations are involved. Sufficient progress can only be expected to be made, if three-dimensional Computational Fluid Dynamics (CFD) codes are applied, due to their good scaling capability. Once a code has been validated, it can generally be adapted for new geometric boundary conditions, since the geometry involved is represented by means of a sufficiently fine nodalisation. For the purposes of code development, new experiments must be carried out to enable calibration of the basic models. New instrumentation with a high 3D resolution is required. The important quantities to be measured are: averaged velocity vector components for both phases, averaged pressures, temperatures and densities, Reynolds stresses for both phases, and several additional parameters describing the interphase surface, such as bubble-related droplet diameters and the location of the free interphase surface, etc. By way of conclusion, the requirements for spatial and time resolution were discussed by means of the example of the hot leg of a pressurised water reactor. In areas where large gradients have to be expected (e.g. near walls) the density of the measuring grid must be increased.

A. Breuer (TSI Aachen) reported on an optical patternator, which is based on a planar laser-induced fluorescence technique (LIF) for the fast characterisation of the quality of injection nozzles (mass flow and droplet diameter distribution). The high efficiency of the test facility allows an application of such a device in quality monitoring in the production process of nozzles. The laser beam is optically widened to create a planar measuring volume. Droplets crossing the illuminated plane are excited to a state of luminescence. The intensity of the luminescence is recorded by a CCD camera in order to determine the droplet diameter distribution. Along with the description of the test facility, numerous potential applications were indicated.

K. Mühlfriedel und *K.-H. Baumann* (Universität Halle) presented the application of LIF for the investigation of material transport in boundary layers located between two immiscible fluid phases (water, organic solvent). A fluorescent dye is dissolved in one of the phases and this is transferred to the other phase via the boundary layer. Illuminated by laser light cut, the dye (tracer) is excited to a state of fluorescence and the instable concentration field rectangular to the interphase surface is recorded by a CCD camera. From the measured data, mass transfer coefficients are derived.

H. Benk and *R. Loth* (TU Darmstadt) developed a method for the application of hot film probes in a two-phase flow (air/water). Two crossed probes are used to measure the two components of the instantaneous velocity of the liquid phase simultaneously. Depending on the flow regime (low or high turbulence), either the sum-difference method, based on a series expansion of first order of the angular sensibility, or a so-called multi-position method is used. A special feature of the signal evaluation is the separation of components that originate from bubble contacts with the probe. This work represents an important contribution to two-phase turbulence measurement techniques.

R. Hampel, *W. Kästner*, *A. Fenske* and *S. Schefter* (HTWS Zittau) reported on model-based methods for the detection of the level in pressure vessels, filled with two-phase mixtures. Traditional measuring methods may produce inadmissible measuring errors during transient processes. This is relevant, for example, where PWR pressurisers or boiling water reactor vessels are involved. The methods presented are based on a physically approximated state model, describing the dynamic system by means of fuzzy-based algorithms. For the adaptation of the model to the real processes observed input and output values are used. Depending on the flow regime, different algorithms (e.g. Karman filters) are applied. In the case of a good level of agreement between observed and measured values non-observable quantities can be derived on the basis of the model.

J. Liebert and *H.-P. Gaul* (Siemens AG/KWU) presented findings on the measurement of steam fraction (void fraction), mass flow and flow pattern detection in the Upper Plenum Test Facility (UPTF) in Mannheim. For this purpose, a special pipe-flow meter was developed. This consists of a tripple-beam gamma densitometer, four fluid force sensors (flow paddles) distributed over the walls of the pipe, and pressure and temperature sensors. The average void fractions, the mass flows and the flow patterns are determined by means of pattern matching algorithms. Assuming different flow patterns, the response of the tripple-beam gamma densitometer and the fluid force sensors was modelled and stored. The actual measuring result is compared with these patterns, and the pattern showing the best level of agreement is selected for the void fraction and mass flow rate calculation. The measuring system has been successfully applied for large horizontal pipelines up to DN750.

The session on impedance methods was opened with the central lecture for this field, given by Prof. *D. Mewes* (Universität Hannover). This was concerned with the visualisation of two-phase flows in bubble column and trickle-bed reactors. In both types of reactors, flow instabilities can occur, when a critical flow rate is exceeded. These instabilities are connected with recirculation areas, and cause unfavorable working conditions. The retention time distribution is widened and, as a result, the quality of the product decreases due to by-product generation. In some cases, by-products can produce deposits in the reactor. Theoretical modelling has predicted the following general behaviour pattern for a bubble column: At low gas flow rates in bubble columns, the bubble rise velocity does not depend on location and time (homogeneous bubble flow). When the flow rate is increased, a transition to heterogeneous bubble flow takes place. Large circulation cells are induced. In the vicinity of the wall, the average liquid velocity shows a downward trend and bubbles are dragged down in this area. The gas fraction in the center increases, and large bubbles are formed. Coalescence is promoted by the vorticity of the liquid flow. These effects have been confirmed by means of a wire-mesh tomograph. This device consists of three planes of wire grids, inserted into the flow with small distances between each other. Each grid consists of 59 thin wires serving as electrodes. The wires of two successive grids include an angle of 120. By measuring the conductivity between all pairs of neighbouring parallel wires, three independent projections of gas fraction distribution in the cross section of the column can be recorded. A tomographic image reconstruction procedure calculates instantaneous gas fraction distributions at a resolution of several mm and approximately 100 frames per second. In addition to this, the author reported on the use of a capacitance tomography sensor, which is used in the trickle bed reactor. this can be applied together with non-conducting packages only. 16 electrodes fixed to the outer surface of the column, form a ring of condenser plates. During measurement, a set of capacitance values for all independent combinations of electrodes is recorded. The reconstruction algorithms are much more complicated for this type of tomography, because of the non-linear behaviour of the sensor. Iterative procedures have to be applied along with a successive approximation of the permittivity distribution. In each iteration, the electrical field has to be calculated using finite element methods. The results presented demonstrate the transition from regular flow, to a flow with recirculation areas in the trickle bed.

P. Horner, *A. Zeisberger* und *F. Mayinger* (Technische Universität München) introduced a new capacitance sensor for local void fraction measurements on packages of spherical particles. The measurement technique is based on the different levels of permittivity in steam and water. An assembly of six small spheres serves as a sensor, and this is mounted between the two legs of a small U-shaped support. The spheres are electrically insulated from the particles of the surrounding packing. The special shape of the sensor enables one to minimise flow distortion. Test measurements with water and R134a have shown an accuracy level of better than 6 %, in comparison with a -densitometer. The sensor is applied in experiments concerned with the cooling of core debris during a core melt-down accident in a nuclear reactor. Five probes were operated simultaneously. The occurrence of large oscillations in the void fraction was established.

F. Dräger, S. Fleischer, R. Hampel (Hochschule für Technik, Wirtschaft und Sozialwesen Zittau/Görlitz) and *H.-M. Prasser* (Forschungszentrum Rossendorf) reported on two applications for capacitance sensors. In the first part of the presentation, *S. Fleischer* discussed the detection of Tailor bubbles in a thin tube of only several mm in diameter. A capacitance sensor consisting of two electrodes was used. The signals were interpreted with regard to the interaction of the bubble with the electrical field between the condenser plates, and then compared with the signals of needle-shaped conductivity probes. Individual bubble sizes and bubble rise velocities were measured. In the second part of the presentation, *F. Dräger* reported on a test series carried out at the two-phase test loop of the Institute for Safety Research in Rossendorf. In a vertical test section, a capacitance tomograph from UMIST Manchester was compared with other measuring techniques: a wire mesh sensor, ultrasonic transducers, a gamma densitometer, an array of 8 needle probes and a radar sensor. The signals of the capacitance measurements were evaluated by means of clustering with a neuronal network. This kind of nonsupervised training procedure allows to classify signals that originate in different flow regimes. It was demonstrated that neuronal networks can be used for establishing flow maps.

T. Kern (Forschungszentrum Rossendorf) reported on needle-shaped conductivity probes for carrying out measurements in gas-liquid foams. It was demonstrated that needle probes provide reliable information on the void fraction and bubble size in foams. The results of experiments, in which needle probes were used to measure vertical void fraction profiles in an air/water bubble column, with a foam zone above the homogeneous bubbly flow were presented. A steady foam zone was achieved by adding small amounts of alcohols such as propanol, butanol or amylalcohol to the liquid. The foam generated was wet and dynamic, i.e. after switching off the gas supply, the foam decayed very quickly, within a few seconds. The results showed a steep rise in the void fraction at the transition from bubbly flow to foam zone. In the foam, the void fraction then climbs slowly to 100 % at the coalescing interface. The bubble frequency decreases in the foam due to coalescence. Both values can be converted to an average bubble diameter. This bubble diameter is at first small and constant in the bubbly flow, and then grows in the foam zone, due to bubble coalescence.

The last presentation was held by *H.-M. Prasser* (Forschungszentrum Rossendorf). Wire mesh sensors developed in Rossendorf have achieved a time resolution of 1024 frames/s, which is high enough for the measurement of bubble size distributions. At moderate velocities in the range up to several m/s, individual gas bubbles are imaged in several successive, instantaneous gas fraction distributions (images). At known transport velocities, the volume of the individual bubbles can be determined by means of so-called recursive fill algorithms, which are derived from image processing. The algorithm starts at a position within the array of measured data, where the local gas fraction is maximal. The bubble volume is calculated by summation of the local gas fractions of all connected neighbouring points, until the edge of the bubble is reached. In a vertical pipeline of 50 mm diameter, the appearance of bimodal bubble size distributions was found to indicate the beginning of the transition from bubble to plug flow. The region of fully developed plug flow is reached, when the effective bubble diameter starts to exceed the pipe diameter. The resolution of bubble size measurement is restricted by the spatial resolution of the wire mesh sensor, which is in the range of 2-3 mm.

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